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October 22, 2015

Defense Technical Information Center
8725 John J. Kingman Road
Suite 0944
Fort Belvoir, VA 22060-6218

RE: Annual report under Grant No.: N000141110450

Dear Sir/Madam:

Enclosed please find our annual report under the above grant. Please let me know if you have any questions or need further information.

Yours sincerely,

Mary Morris

Mary Morris
Contract Administrator

Enclosure: Annual report

REPORT DOCUMENTATION PAGE

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14. ABSTRACT
Work continued on the evaluation and development of the Eddy Diffusivity Mass Flux (EDMF) parameterization of turbulence and convective mixing in numerical models. The main focus was in using previously obtained Twin Otter Doppler Wind Lidar (TODWL) data near Monterey, CA and Dugway, UT to investigate the physical characteristics, TKE transports and contributions to EDMF parameterization by boundary layer rolls and near surface "turbulence channels. A triad model was updated and modified to simulate rolls (including stacked rolls) in preparation for modifying current EDMF expressions We also continued to investigate the sensitivity of the WRF and COAMPS model to modified EDMF.

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OLE, EDMF, Doppler Wind Lidar

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Investigation of the Representation of OLEs and Terrain Effects within the Coastal Zone in the EDMF Parameterization Scheme: An Airborne Doppler Wind Lidar Perspective

Annual Report
Under Grant No.: N000141110450

Covering the Period:
30 June 2014 – 30 September 2015

Submitted by:

Simpson Weather Associates, Inc.
809 E. Jefferson Street
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21 October 2015

1. Introduction

The general objective of the fourth year of our research was to continue to contribute to the evaluation and development of the Eddy Diffusivity Mass Flux (EDMF) parameterization of turbulence and convective mixing in numerical models.

As during the previous years, we have focused on using data taken near Monterey, CA from the Navy Postgraduate School's airborne Twin Otter Doppler Wind Lidar (TODWL) and, in one single case, data derived from the flux-measuring Controlled Towed Vehicle (CTV). This year we used archived data from 2007 TODWL missions off the coast of Monterey to document the presence of the vertical channels of turbulence associated with boundary layer rolls. In addition, we have been analyzing TODWL data taken during the 2012 MATERHORN project near Dugway, UT in order to study flow in complex terrain.

As reported previously, the TODWL flights have frequently revealed the presence of shear generated OLEs (Organized Large Eddies) and rolls in the Boundary Layer that interact with and are presumably modified by coastal jets over the ocean and thermally driven flows over mountains. Interactions between the topography, the coastal zone, and the atmospheric boundary layer play an important role in the evolution and structure of OLEs that contribute significantly to mass, energy, and momentum fluxes in the boundary layer. Investigation of this same TODWL data has also revealed "turbulence channels" sandwiched between boundary layer rolls that appear to be conduits for delivering turbulent energy to the upper part of the MBL without significant dissipation.

The bulk of our data analysis and research during the fourth year of the study continued this work and focused on the characterization of these rolls/OLEs and "turbulence channels" as well as their impact on EDMF. To gauge the latter, we tried to answer questions such as:

- Is the EDMF formulation adequate for accounting for the flux enhancements due to OLEs in various degrees and modes of organization?
- If not, is there an addition term that can be added to the EDMF expression that better represents the contributions of shear generated rolls as opposed to convective organization?

In addition to the analysis of real TODWL data, we (mainly Ralph Foster at UW) have been modifying his phenomenological model to handle the complex MBL situations of stacked rolls and turbulence channels being revealed by the TODWL. Foster continued to improve his phenomenological model of OLEs and begun developed a likely theoretical interpretation for these features with an eye toward the EDMF modeling framework. This included extending the wave-wave roll interaction model to allow non-collinear models to interact.

During the fourth year, the TODWL data was also utilized by both the WRF and COAMPS model to help characterize and understand low level wind fields and turbulence in complex terrain, as well as the contribution of OLEs to turbulent fluxes in the EDMF scheme.

A detailed description of the main results of the data analysis, OLE phenomenological modeling and numerical modeling studies is provided in the next section. A listing of papers and presentations is given in Section 3.

2. Results

Figure 1, taken from a presentation given at the ONR DRI workshop in Monterey, August 19-21, 2015, briefly summarizes our main achievements and research of the past year. These results and activities are presented in more detail in the following sections and a copy of the original presentation is provide in Attachment A.

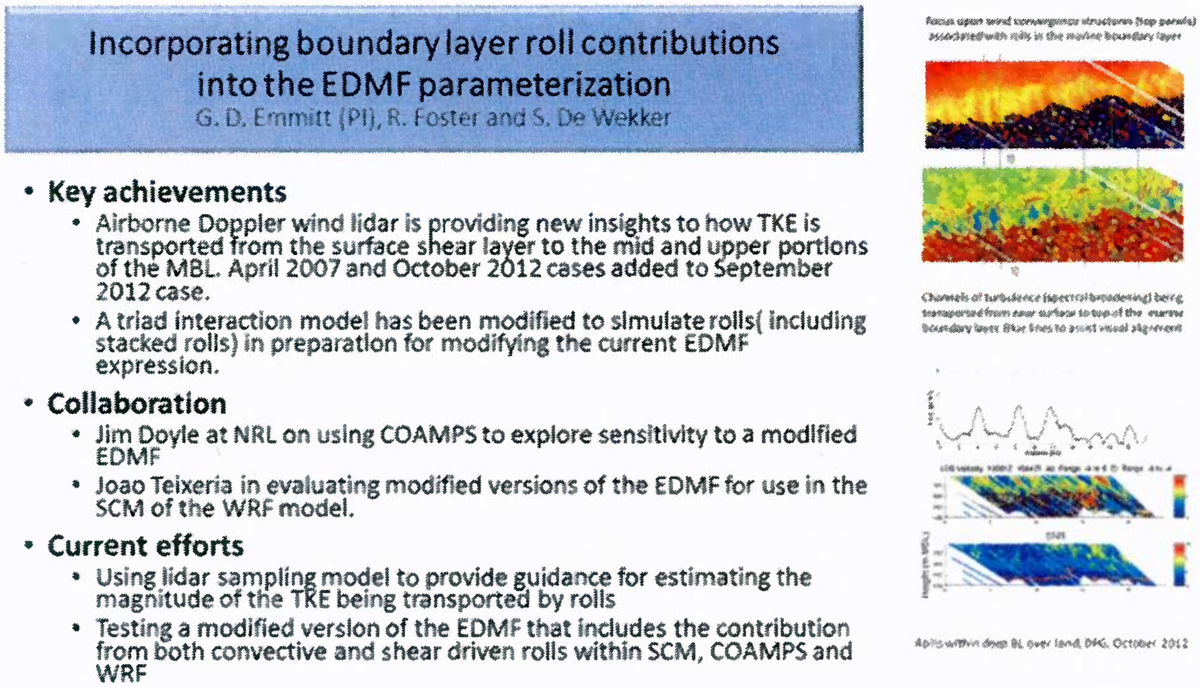


Figure 1: Summary of key achievements and results over the past year's EDMF parameterization study.

2.1 Physical Characterization of OLEs over water and land (SWA lead)

A presentation summarizing the below results was given to ONR Project managers in August, 2015 in Washington, DC and is provided in Attachment A.

Using data taken by the Twin Otter Doppler Wind Lidar (TODWL) we were able to provide a physical characterization of boundary layer roll circulations or OLE and to provide new insights into how TKE is transported from the surface shear layer to the mid and upper portions of the MBL. In particular, we used a lidar sampling model to provide guidance for estimating the magnitude of the TKE being transported by rolls or OLEs.

This was done utilizing TODWL and CTV data from September-October 2012 (as part of the MATERHORN project), as well as TODWL data near the Salinas Valley taken in April 2007 and October 2012. This data analysis included feature prospecting using a very shallow angle below the horizon (~ -1 -3 degrees for a 300m flight altitude) and resulted in ~ 1 -2 m vertical resolution and 50 m horizontal resolution with ~10 meter sliding sample. Each 100 m blow the aircraft was profiled in about 40 seconds.

Studying the off-shore and coastal (near Monterey, CA) data from September 2012 and April 2007 allowed us to provide a general physical characterization of the boundary layer rolls over the ocean with a focus on TKE channels. This characterization included the following:

- General description
  - Only in regions of convergence, no exceptions found in available data
  - Usually detectable via aerosol backscatter structures; aerosol structures appear to outlast velocity structures; same goes for TKE channels.
  - Lidar suggestions that the channels are more slab like than plume-like; consistent with roll geometry.
- Width of turbulence channels
  - 50 -100m with very little broadening throughout vertical extent
- Vertical extent of channels
  - Usually starting very near the surface, but not always (stacked rolls)
  - Not all channels are traceable from surface to top of BL (best described with a PDF)
- Turbulence intensity
  - Difficult to interpret from spectral broadening (SB).
  - Contrast ratio with adjacent SB fairly consistent at 2 – 3 m/s
- Vertical velocities
  - Based upon 2-D convergence calculations, w ranges from .5 – 3.5 m/s
  - Based upon CTV flown at low altitudes (~50 m), very hard to measure but on order .2 - .5 m/s

We also investigated the role and characterization of rolls in deep convective boundary layers over land by studying TODWL prospecting data near Dugway, UT taken during the Sept-Oct 2012 MATERHORN project and TODWL flights in the Salinas Valley from November 2007.
Unlike over the water, in general, we found that roll features were difficult to distinguish in lidar output over land although regions of increased LOS velocity could be linked to a maxima in the TKE field.

As mentioned in Section 1, we also investigated the possibility of modifying the EDMF to incorporate the flux transport due to PBL-scale OLEs that are not solely convective in origin. We found the following:

- Consistent with OLE theory, MF parameterization enhances near-surface wind and reduces near-surface inflow
- MF diffusions contribution to *tke* equation is relatively weak (for this largely shear-driven case)
- MF parameterization is very sensitive to lateral entrainment
- OLE horizontal velocity perturbations are not exactly in phase with vertical velocity perturbations
- Bottom-up focus is inconsistent with OLE dependence on full PBL profiles

2.2 Modeling of OLEs and utilization in EDMF (UW lead)

The standard eddy-diffusivity mass-flux (EDMF) parameterization is designed to capture the non-local planetary boundary layer (PBL) transport induced by organized large eddies (OLE) in strongly (surface-driven) convective conditions. In terms of the vertical velocity, such PBLs are highly skewed with strong and narrow updrafts surrounded by much broader and weaker downdrafts. The updrafts are capable of efficiently transporting enthalpy (and likely momentum) from the surface to the upper part of the PBL. The mass-flux contribution to the EDMF model is designed to capture this enthalpy flux. The MF concept is that the plume enthalpy retains much of the surface value through its ascent. While the actual lateral diffusion of this plume enthalpy is described by a high-order system of partial differential equations (the combined momentum and enthalpy transport equations), it may be effectively represented by a simpler first-order ordinary differential equation that says the vertical change in the interior properties are proportional to the difference between the overall mean and the mean within the plume. Based on LES model studies, the dimensional proportionality factor has a typical value of $\varepsilon \sim 10^{-3}(m^{-1})$. The EDMF model calculates this factor as a function of the eddy-diffusivity model's estimate of the turbulent kinetic energy (TKE). It should be noted that MF contribution assumes that the updraft fraction is always $\sigma = 0.1$, which is typical for pure convective conditions (i.e., no mean wind). The ED contribution uses a mixing length formulation based on a TKE transport equation.

Our observations show that the nearly neutrally stratified PBL prefers to form OLE in the form of approximately wind-aligned roll vortices that are highly coherent along the roll axes. Rolls are characterized by long lines of relatively strong updrafts compensated by weaker downdrafts. Consequently, the skewness, in terms of the vertical velocity is much less than for a convective PBL. However, the observations suggest that these roll updraft lines may be an efficient transport of turbulence across the PBL. Hence, we investigated ways to incorporate this non-local transport within the framework of the EDMF parameterization. Previous work by Zhu (2008) used WRF-LES runs to investigate the MF-like transport of momentum by PBL rolls for hurricane conditions. He used a similar first-order ordinary differential equation for the vertical change in updraft properties to find that dimensional lateral diffusion parameter has a much larger value than is used in the EDMF, i.e. $\varepsilon_m \sim 10^{-2}(m^{-1})$.

We were provided a Matlab implementation of the EDMF model. We confirmed that it could reproduce the results from Witek et al. (2011ab). To make the modifications as simple as possible, we followed the framework of associating the roll OLE updrafts with the local surface properties. We maintained the same ED formulation. There were three major modifications. First, for simplicity we assumed that the dimensional lateral diffusion for momentum is proportional to that calculated for enthalpy and made that constant of proportionality an input parameter. Second, we added the mass flux contributions to the EDMF model's momentum equations. Third, we added the mass flux contribution to the vertical velocity variance to the EDMF models TKE equation. For the purely convective case, this contribution is negligible because the updraft fraction is forced to be 10% and the "weighting factor for this contribution works out to be $1 - \left(\frac{\sigma}{1-\sigma}\right)^2$. However, for roll OLE conditions, values of $\sigma \sim 0.3$ are typical.

An important guide to the implementation of roll OLE in the EDMF model are the solutions to the eighth-order coupled triad model for rolls that have been described in previous reports. We have continued to modify this model to simulate rolls (including stacked rolls) in order to modify the current EDMF expressions. From these, we have a strong sense of how the rolls affect the mean flow profiles. As a test case, we assumed mean conditions typical for the PBL and examined how the effects of the modified EDMF parameterization on the mean wind profiles, primarily as a function of the dimensional lateral diffusion constant. Consistent with the WRF-LES results of Zhu (2008), we find that its value should be on the order of fifty times that for enthalpy. Overall we find that the roll-OLE EDMF model increases the mean near-surface wind speed (implying higher surface fluxes). Furthermore, it reduces the near-surface inflow. These results are both consistent with the previously reported calculations and with recent research reported by Gao and Ginis that was performed as part of this DRI. The roll-modified mean flow profiles in Gao and Ginis are quite consistent with the theoretical model of Foster (2005). The implication is that the nonlocal contribution to the PBL transport in near-neutral conditions is important and that the EDMF modeling framework should be extended to include the effects of roll OLE that generally form in the nearly neutral PBL with moderate to strong mean wind. For example, this is a typical PBL state over much of the oceanic environment.

It did become clear that the roll OLE MF contribution should be modeled differently than basing it on the local surface fluxes. PBL roll characteristics are not determined by the local surface fluxes. Instead, they depend on the full mean flow profiles of wind and virtual temperature. They affect the surface fluxes both in the mean (by generating a net enhancement of the overall mean surface wind) and locally (by reducing or enhancing the local surface wind parallel to the axes of strong updraft regions. But, the surface flux modifications should be considered as a response to the formation of rolls rather than an initiation factor. The phasing has the highest near-surface wind perturbation offset from the maximum vertical velocity. The bottom-up MF parameterization for pure convection is the correct method for these conditions. However, we must investigate how best to parameterize the roll MF contribution in a manner that is not based on the surface fluxes.

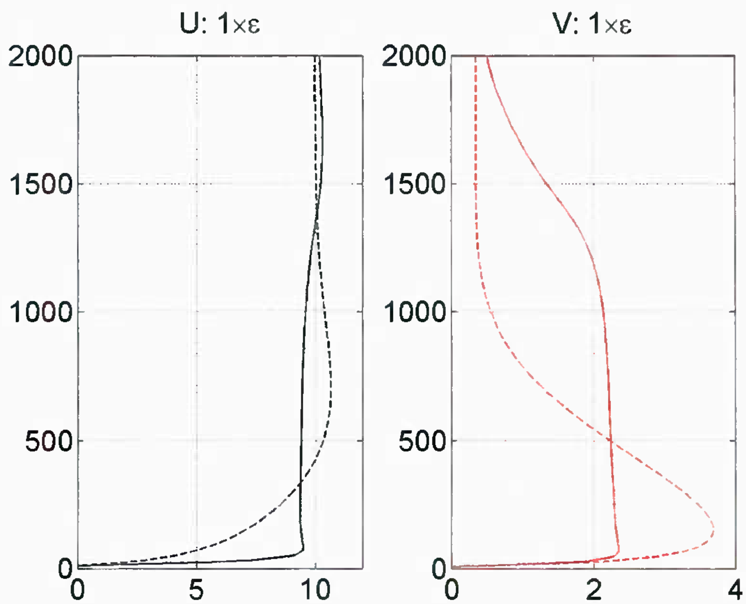


Figure 2: Modified EDMF mean wind profiles (solid lines) calculated assuming that the lateral diffusion coefficient for momentum is the same as for enthalpy. The dashed lines are the initial mean flow profiles.

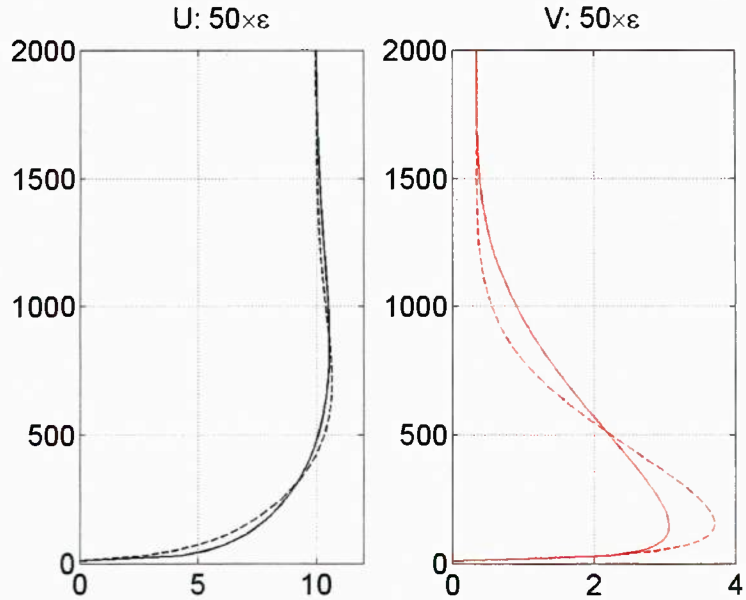


Figure 3: As in Figure 2, but assuming that the lateral diffusion coefficient for momentum is fifty times that for enthalpy.

References:

Foster RC 2005: Why rolls are prevalent in the hurricane boundary layer, J. Atmos. Sci. 62, 2647-2661

Witek et al. 2011a: An Integrated TKE-Based Eddy Diffusivity/Mass Flux Boundary Layer Closure for the Dry Convective Boundary Layer, J Atmos. Sci, 68 1526-1540

Witek et al. 2011b: An Eddy Diffusivity–Mass Flux Approach to the Vertical Transport of Turbulent Kinetic Energy in Convective Boundary Layers, J Atmos Sci, 68, 2385-2394.

Zhu, P 2008: Simulation and parameterization of the turbulent transport in the hurricane boundary layer by large eddies, J. Geophys Res., VOL. 113, D17104, doi:10.1029/2007JD009643

2.3 Investigation of turbulence and boundary layer structure over land (UVA lead)

The numerical modeling activities were focused on investigating the turbulence and boundary layer structure over land, in particular during the ONR funded MATERHORN field campaign. Tasks during this reporting period included:

1) Analysis of turbulence obtained from the standard instruments on the Twin Otter

2) Analysis of airborne Doppler Wind Lidar to investigate spatial boundary layer structure

3) Collaboration with NRL on using COAMPS-EDMF

4) Preparation for participation in MURI – CASPER-EAST field experiment

The UVA contribution was focused on investigating of turbulence and boundary layer structure over land, in particular during the ONR funded MATERHORN field campaign. Student Mark Sghiatti made progress in his MS research to analyze turbulence kinetic energy (TKE) from in-situ Twin Otter data and to calculate components of the turbulence kinetic energy budget. Some emphasis was also put on the observation of features that suggest the presence of convective rolls. An example of these observations is shown in Figure 4.

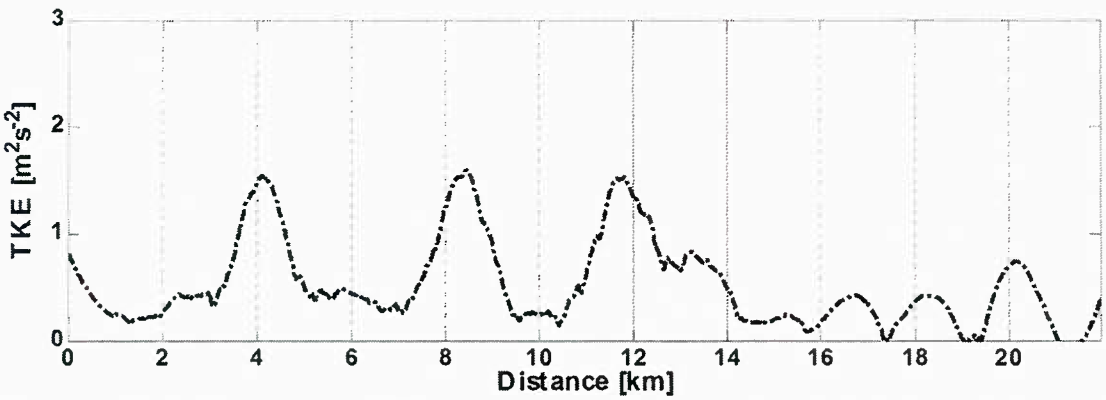


Figure 4: Twin Otter in-situ TKE measurements over an individual flight path during MATERHORN.

The TKE field on this particular flight leg shows three maxima in the TKE field at a regular horizontal distance of about 2.5-3 km . The underlying terrain of this region is relatively flat, and therefore variability in the underlying topography is not expected to have influenced the TKE. Instead, over flat terrain much of the TKE is expected to be generated from vertical motion induced by turbulent structures including thermals and convective rolls. Previous studies have found ratios of thermal or convective roll wavelength (λ) to CBL depth on the order of 2.2-6.5. The aspect ratio in this study is 4.38 (λ =3.5 km, CBL depth =0.8 km), which is within range of observed aspect ratios associated with convective rolls. Because of the sinusoidal nature of the TKE field, we suspect that that convective features within the CBL could have contributed to the production of TKE. We have started to investigate the origin and thermodynamic structure of these features in order to determine if they are an important phenomena for affecting TKE in complex topography.

Post-doctoral research associate Sandip Pal continued the analysis of PBL heights from the TODWL data for all research flights and submitted a paper to the Journal of Applied Meteorology and Climatology.

Dr. Yi Jin and Jim Doyle at NRL have recently implemented the EDMF parameterization in COAMPS and some test simulations have been performed for a BOMEX case. During the next year, the collaboration will be enhanced and simulations will be performed for selected case studies in MATERHORN. A major goal will be to investigate the impact of the EDMF parameterization in simulations over complex terrain areas. In addition UVA and SWA have also worked with NRL (Teixeria) in evaluating modified versions of the EDMF for use in the SCM of the WRF model.

Preparations were made to participate in the ONR funded CASPER-EAST experiment. One of the goals of the UVA team (two MS students: Nathan Rose and Ross Palomaki) is to investigate organized boundary layer structures and their impact on electromagnetic wave propagation over open waters. UVA will participate using multi-rotor for the profiling of temperature, humidity, and wind.

3. Papers and Presentations

De Wekker, S.F.J., and S. Serafin, 2014: Understanding the spatial variability of convective boundary layer depth around an isolated mountain with a factor separation approach. 16th AMS Conference on Mountain Meteorology, 17-22 August, 2014, San Diego, CA.

De Wekker, S.F.J., 2015: Development of an autonomous multi-rotor copter for vertical profiling in the atmospheric boundary layer. 3rd annual meeting of the International Society for Atmospheric Research Using Remotely piloted Aircraft (ISARRA), Norman Oklahoma, USA, 20-22 May 2015.

Emmitt, G.D., R C. Foster, S.F.J. De Wekker, and K.S. Godwin, 2015: Airborne Doppler Wind Lidar investigations of OLEs and LLJs in the marine boundary layer and their implications for flux parameterization. 19th Conference on Air-Sea Interaction, 4-8 January 2015, Phoenix, AZ.

Knievel, J.C., Y. Liu, S.F.J. De Wekker, W.Y.Y. Cheng, Y. Liu, and J. C. Pace, 2014: Simulations of meso-gamma-scale circulations near Granite Peak, Utah with NCAR's WRF-based 4DWX system and assimilated airborne lidar data from the MATERHORN 2012 field campaign. 16th AMS Conference on Mountain Meteorology, 17-22 August, 2014, San Diego, CA.

Pal, S., S.F.J. De Wekker, M. Sghiatti, and G. D. Emmitt, 2015: Investigation of the Spatial Variability of the Atmospheric Boundary Layer Heights over an Isolated Mountain: Selected Results from the MATERHORN-2012 Experiment. 17th Symposium on Lidar Atmospheric Applications, 4-8 January 2015, Phoenix, AZ.

Pal, S., S.F.J. De Wekker, and G. D. Emmitt, 2014: Spatial Variability of the Atmospheric Boundary Layer Height over an Isolated Mountain: Selected Cases from the MATERHORN-2012 Field Experiment. 16th AMS Conference on Mountain Meteorology, 17-22 August, 2014, San Diego, CA.

Sghiatti, M., S. Pal, G. D. Emmitt, and S.F.J. De Wekker, 2014: Spatial variability of turbulent kinetic energy and the turbulent fluxes in a daytime boundary layer around an isolated mountain. 16th AMS Conference on Mountain Meteorology, 17-22 August, 2014, San Diego, CA.

4. Plans for FY2016

During the next year (pending funding), we intend to concentrate on expanding the documentation and modelling of the TKE channels. To do this, we will attempt the following:

- Finish the compilation of the summary document of MBL OLEs as observed with an Airborne Doppler Wind Lidar over coastal waters.

- Construct PDF description of OLE features
    - Physical dimensions (including % coverage)
    - Energetics (e.g. PDF of w at Zi/2)
- Publish a paper (Emmitt and Foster) on the TKE channels
- Finish two papers in progress at UVA (de Wekker, Emmitt and Pal; de Wekker, Emmitt and Marks)
- Design and conduct an airborne field experiment for the Spring of 2016 to address the following questions:
    - How do the momentum and enthalpy fluxes vary within the ADWL resolved features associated with MBL rolls?
    - Are stacked rolls common with MBL jets? If so, what are the impacts on the mass flux parametrizations? Do LES models properly capture the energetics and transports of these features?
    - What attributes of the rolls seen with the ADWL are adequately represented by the EDMF (current form); which are not and merit incorporation into the EDMF parameterization?

Attachment A

Incorporating Boundary Layer Roll Contributions into the EDMF Parameterization

Presented at ONR DRI Workshop in Monterey, CA

August 19-21, 2015

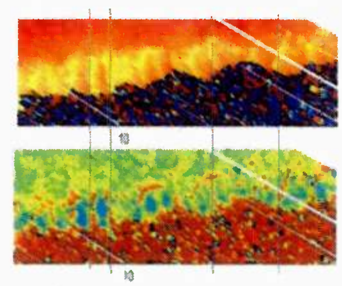
G. D. Emmitt (PI), R. Foster and S. De Wekker

Incorporating boundary layer roll contributions into the EDMF parameterization

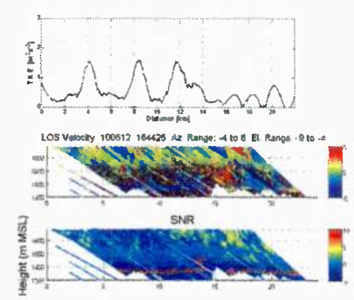
G. D. Emmitt (PI), R. Foster and S. De Wekker

- **Key achievements**
  - Airborne Doppler wind lidar is providing new insights to how TKE is transported from the surface shear layer to the mid and upper portions of the MBL. April 2007 and October 2012 cases added to September 2012 case.
  - A triad interaction model has been modified to simulate rolls(including stacked rolls) in preparation for modifying the current EDMF expression.
- **Collaboration**
  - Jim Doyle at NRL on using COAMPS to explore sensitivity to a modified EDMF
  - Joao Teixeria in evaluating modified versions of the EDMF for use in the SCM of the WRF model.
- **Current efforts**
  - Using lidar sampling model to provide guidance for estimating the magnitude of the TKE being transported by rolls
  - Testing a modified version of the EDMF that includes the contribution from both convective and shear driven rolls within SCM, COAMPS and WRF

Focus upon wind convergence structures (top panels) associated with rolls in the marine boundary layer



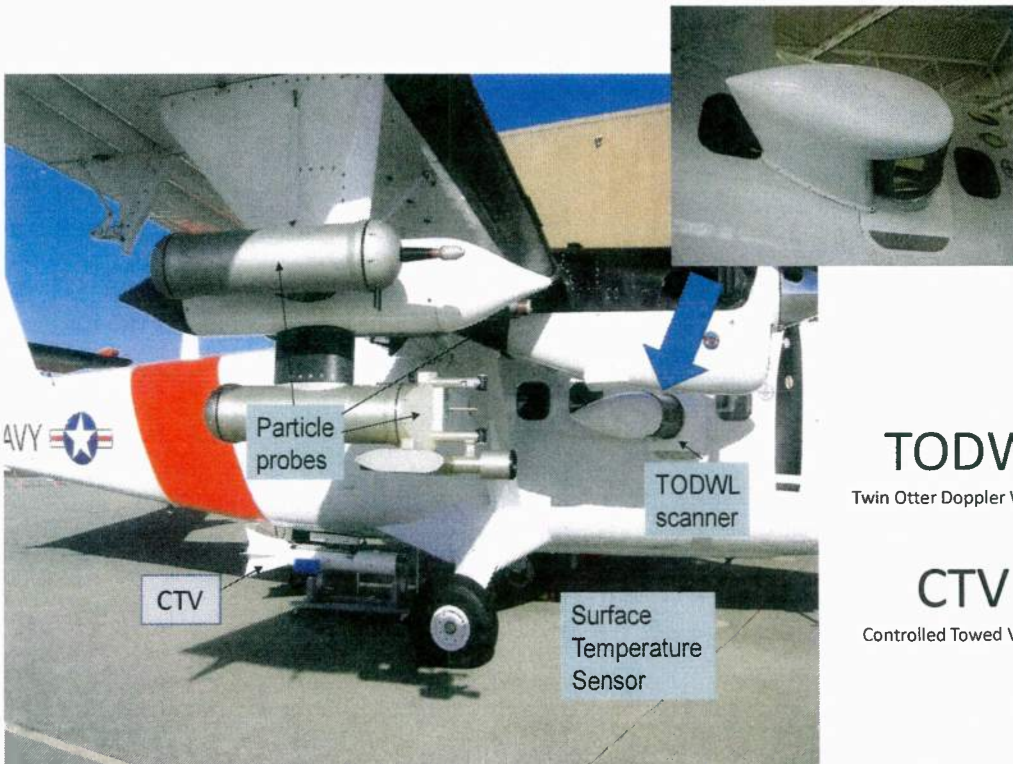
Channels of turbulence (spectral broadening) being transported from near surface to top of the marine boundary layer. Blue lines to assist visual alignment.



Rolls within deep BL over land; DPG, October 2012

Outline

- Physical characterization of BL rolls as observed with an ADWL (Emmitt)
- Investigating ADWL resolved rolls over land (de Wekker and Emmitt)
- Modifying the EDMF to incorporate the flux transport due to PBL-scale OLEs that are not solely convective in origin. (Foster)
- Related investigations
  - PolarWinds (Emmitt, PI)
  - NOAA P3DWL (Emmitt, Dunion, Zhang and Bucci)
  - Possible April '16 extension of BL roll study using Twin Otter (maybe a second DWL)



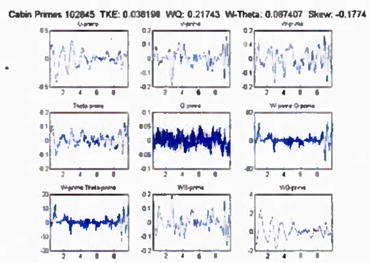
TODWL

Twin Otter Doppler Wind Lidar

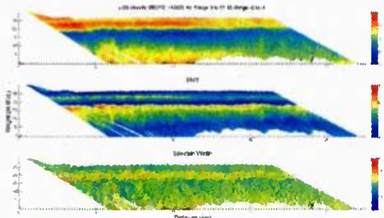
CTV

Controlled Towed Vehicle

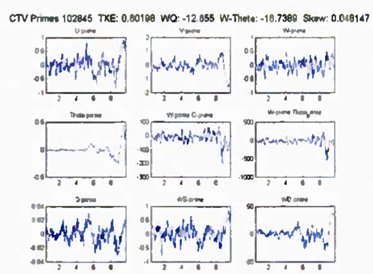
CIRPAS Twin Otter with CTV below



Twin Otter Probe Data



TODWL Time/height Cross sections



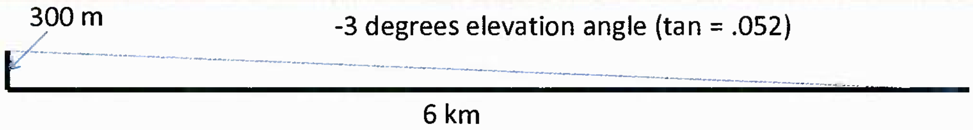
Towed Vehicle Flux Data

SWA

Structure prospecting with DWL

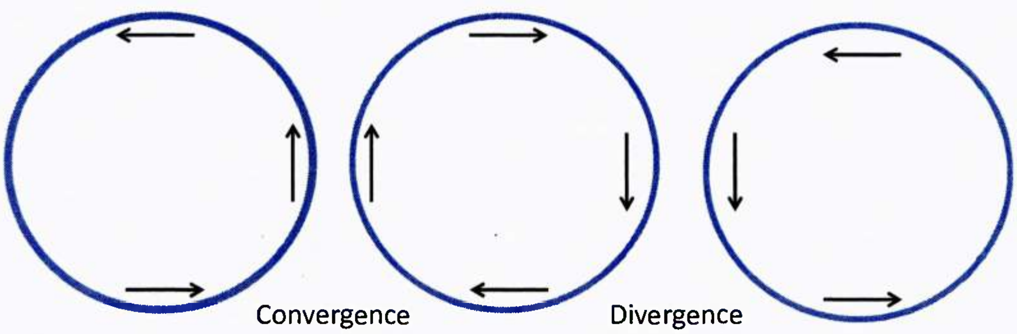
- Feature prospecting uses a very shallow angle below the horizon (~ -1 -3 degrees for a 300m flight altitude).
  - Results in ~ 1 -2 m vertical resolution and 50 m horizontal resolution with ~10 meter sliding sample.
  - It takes ~ 40 seconds to profile 100 meters below the aircraft.

TODWL prospecting geometries



Metric	Value
Twin Otter flight altitude	300 m MSL
Scan configuration	Straight ahead and down 1 -3^{o}
Range gate length	50 m
Twin Otter ground speed	50 -60 m/s
Shot frequency	160/second
Shot integration (data granule)	100 (~ 40 meters forward motion)
Vertical increment between granules	~2 m
Time to sample 100 m vertical	~ 30 - 40 seconds nominally

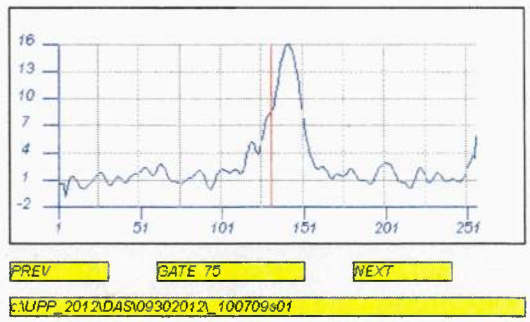
Idealized rolls

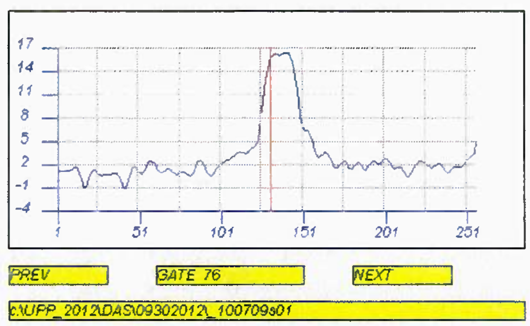


Spectral analyses of TODWL data

The TODWL is a 2 micron, eyesafe coherent detection lidar. The returning signal is heterodyned with a local optical oscillator and then digitized (200 MHz). An FFT is used to process the resulting time series with 50m line-of-sight resolution. In homogeneous flows, a single spectral feature (top figure) is identified as the frequency representation of the radial wind speed.

When probing a turbulent and/or highly sheared environment, the spectral feature is broadened. It is this broadening that we desire to use for estimating turbulence on scales of 25 -100 meters with multi-pulse integrations over 50 - 200

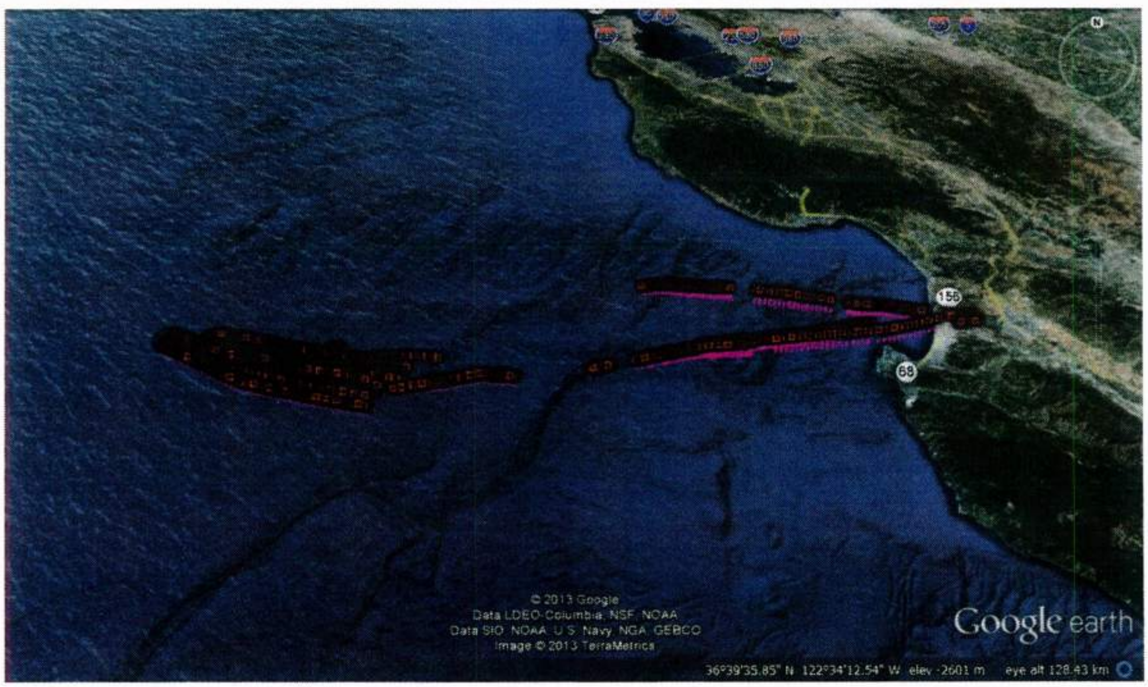


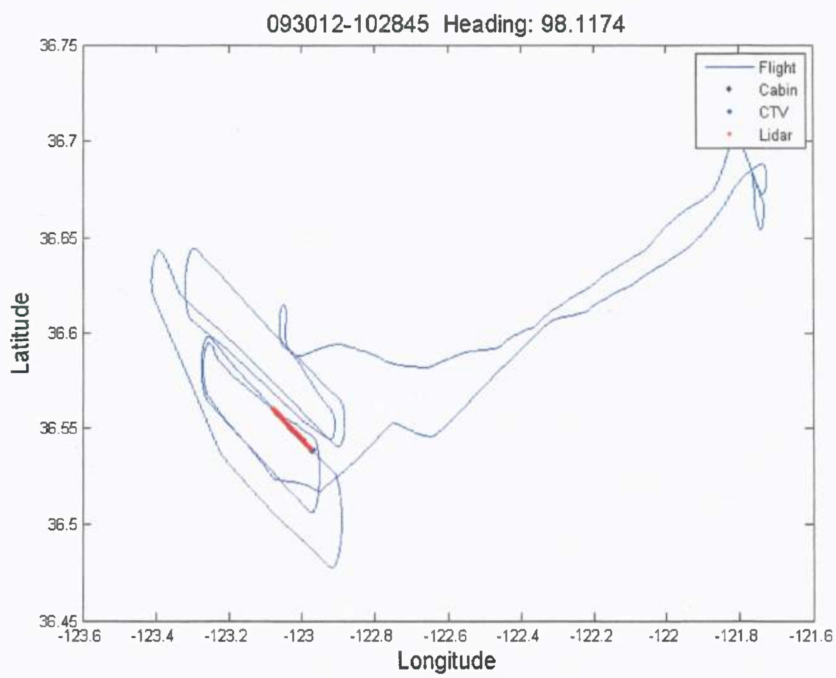


Review of 093012 cases

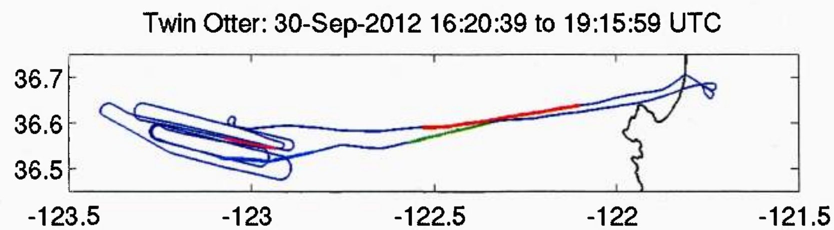
- Only case from 2012 EDMF field campaign
- Twin Otter Doppler Wind Lidar (TODWL)
- Controlled Towed Vehicle (CTV)
- Twin Otter flux instrumentation

Flight path

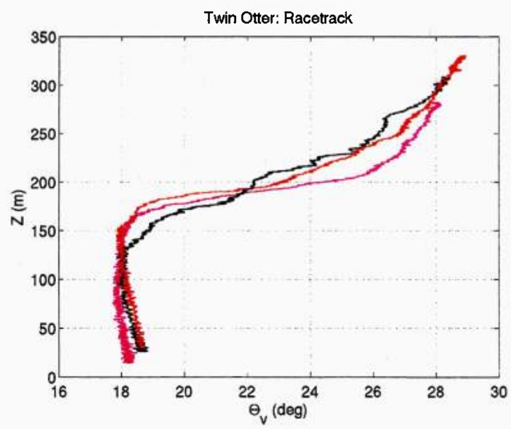

156
68
© 2013 Google
Data LDEO-Columbia, NSF, NOAA
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2013 TerraMetrics
Google earth
36°39'35.85" N 122°34'12.54" W elev -2601 m eye alt 128.43 km

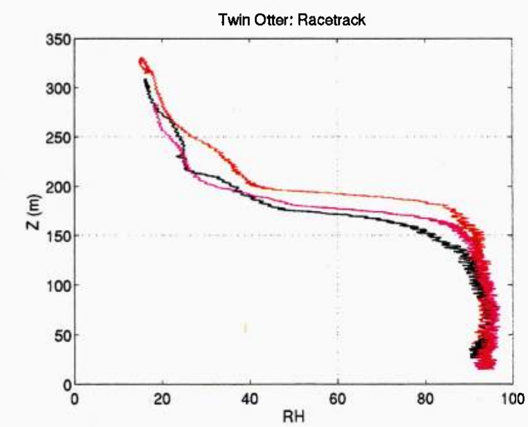


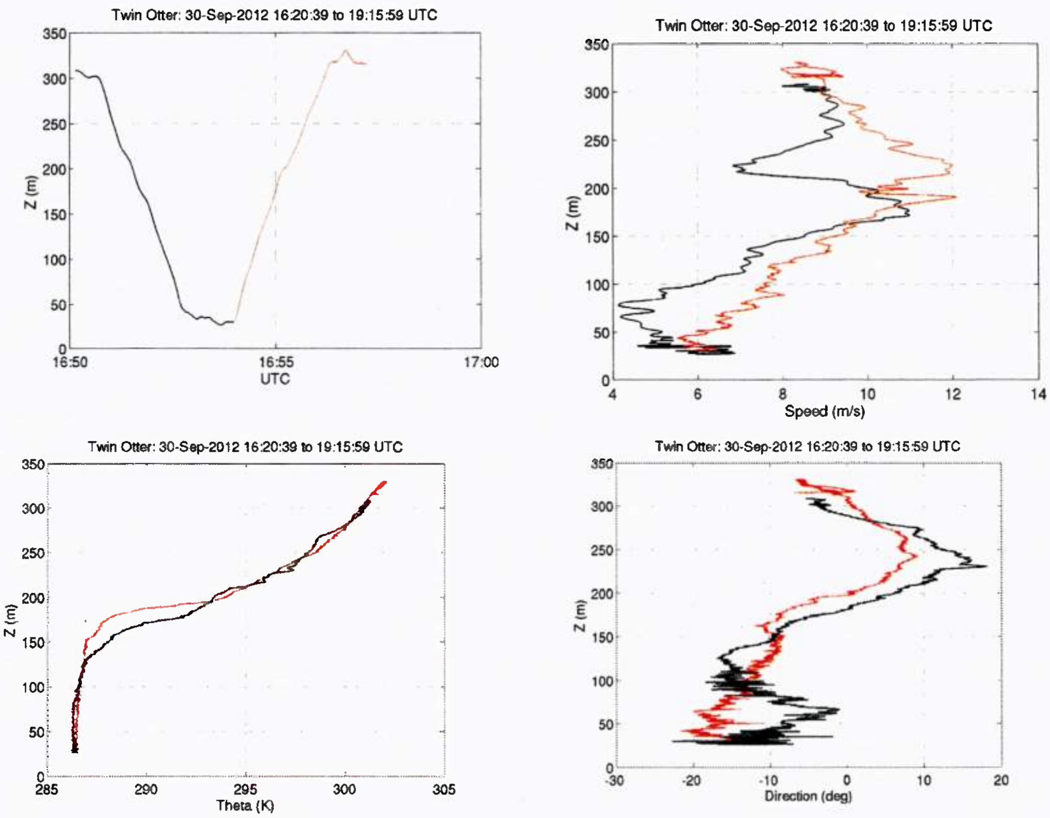
093012-102845 Heading: 98.1174
Flight
Cabin
CTV
Lidar
Latitude
Longitude
36.75
36.7
36.65
36.6
36.55
36.5
36.45
-123.6
-123.4
-123.2
-123
-122.8
-122.6
-122.4
-122.2
-122
-121.8
-121.6

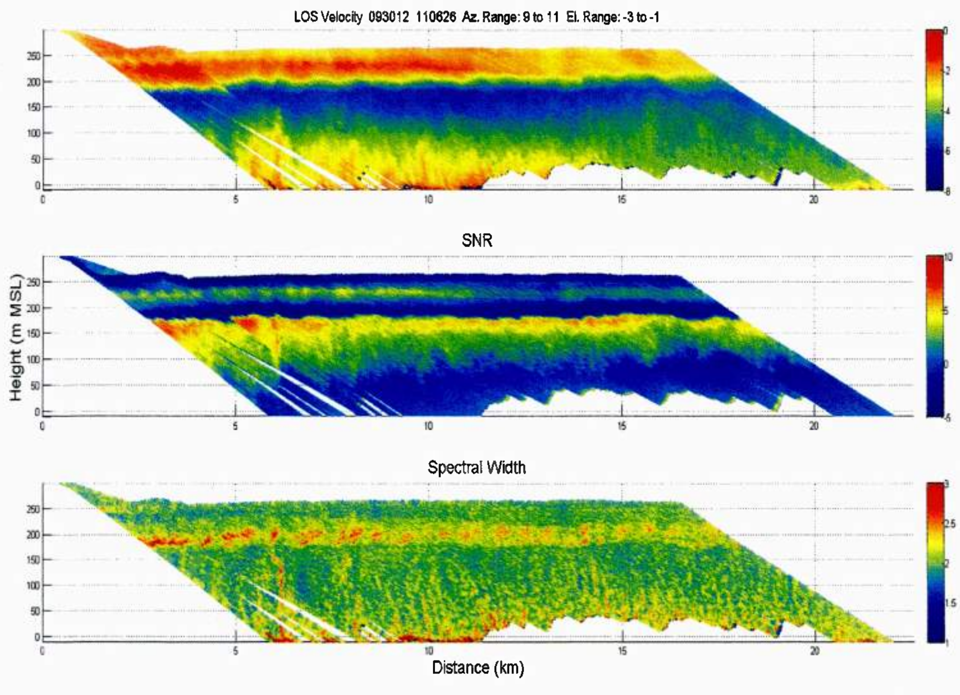


Mean wind at flight level is generally from the north

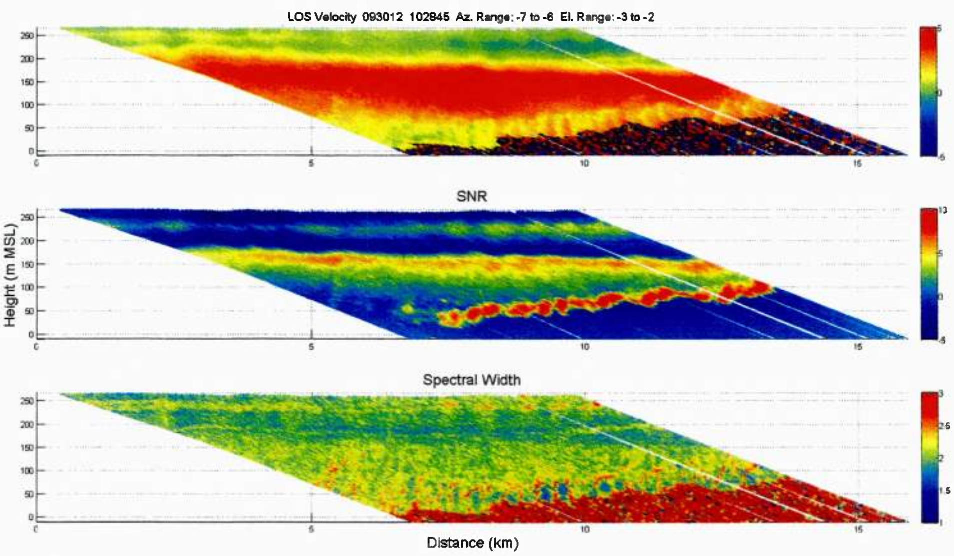


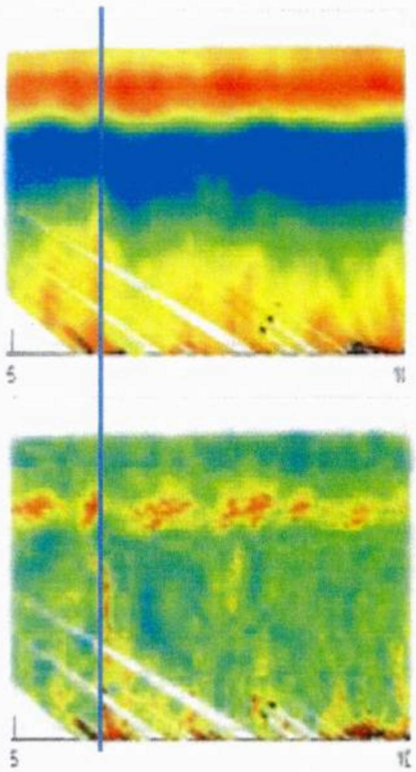



Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
UTC
Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
Speed (m/s)
Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
Theta (K)
Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
Direction (deg)



LOS Velocity 093012 110626 Az. Range: 9 to 11 El. Range: -3 to -1
SNR
Height (m MSL)
Spectral Width
Distance (km)


LOS Velocity 093012 102845 Az. Range: -7 to -6 El. Range: -3 to -2
SNR
Spectral Width
Height (m MSL)
Distance (km)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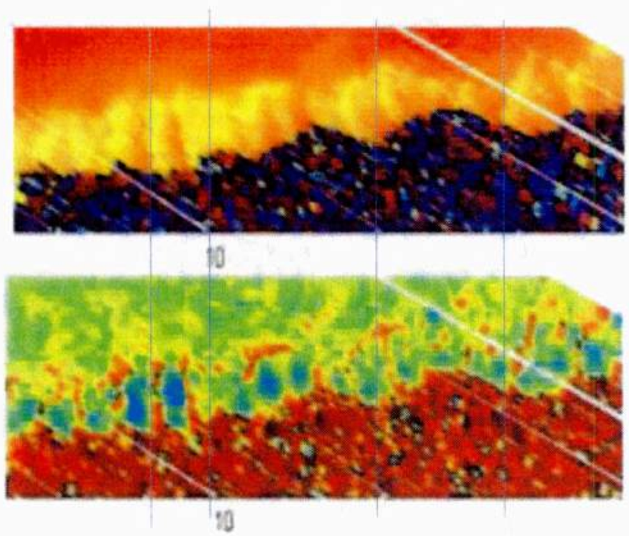
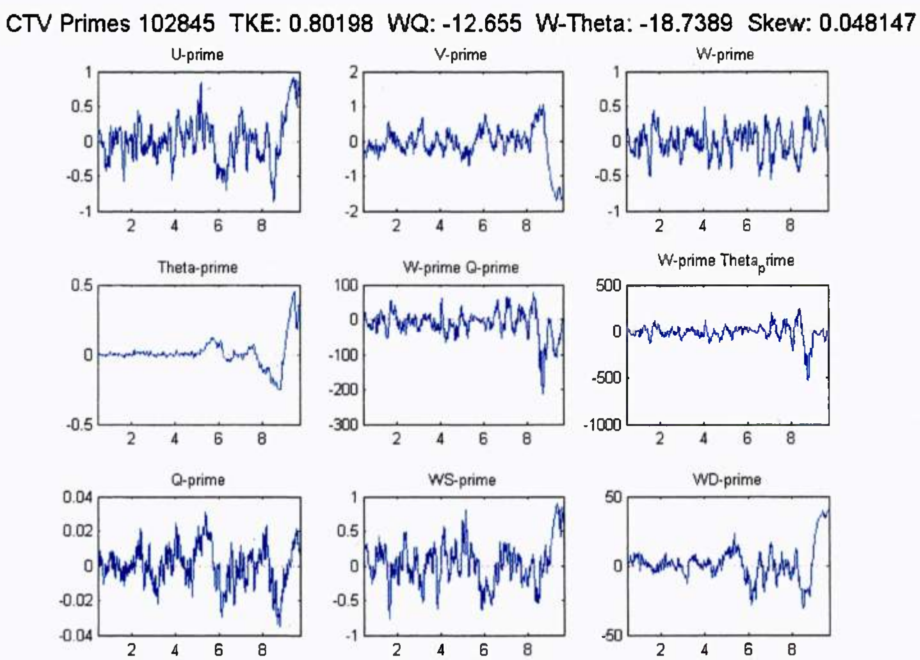
5

10
10

Line density of SB channels (per 10 km)

Flight Segment	SB Channels	Horizontal Convergence zones
1007	25	25
1017	42	42
1028	30	30
1106	28	28
1111	16	16
1121	26	26

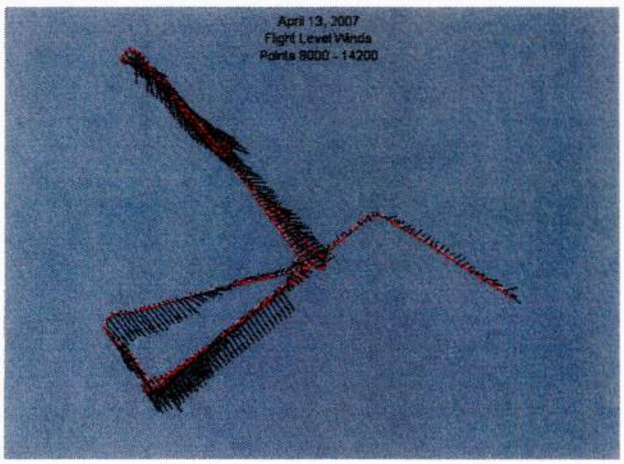


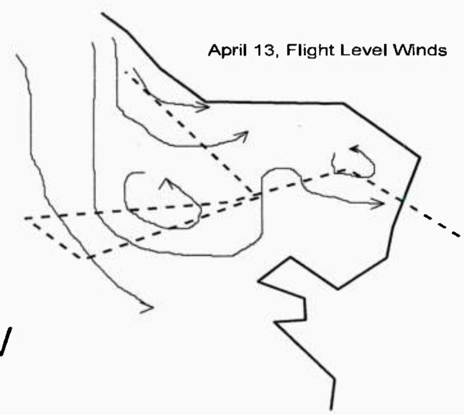
Data and cross products derived from the CTV observations taken during 09/30/15 missions.
The horizontal axis units are km from the start of the data file. Vertical axes vary depending upon parameter

Summary of flight segment statistics

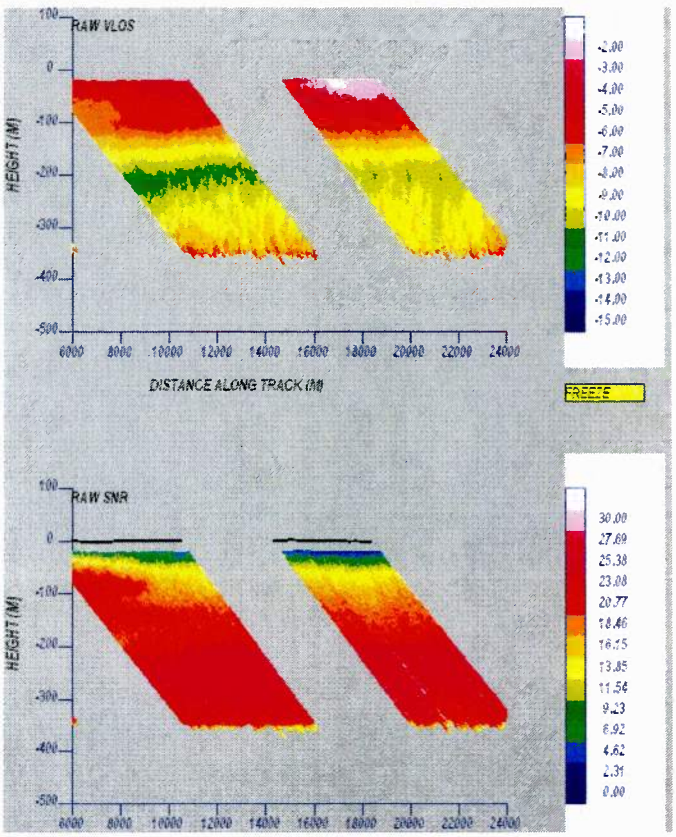
Flight Segment	TODWL Altitude	CTV Altitude	Heading	TKE	Sensible Heat (W)	Latent Heat (W)	Skewness
1007	284	60	94	.19	8.55	3.43	-.40
				1.92	-1.28	15.15	.90
1028	292	25	98	.04	.22	.09	-.18
				.80	-12.6	-18.7	.05
1106	286	75	294	.05	3.02	1.21	-.51
				1.1	-3.36	-1.19	-.17
1111	290	75	293	.24	1.98	.80	-.37
				.29	-.74	.55	.22
1121	288	climbing	98	.14	-1.11	-.44	.90

Mining of April 2007 TODWL flights

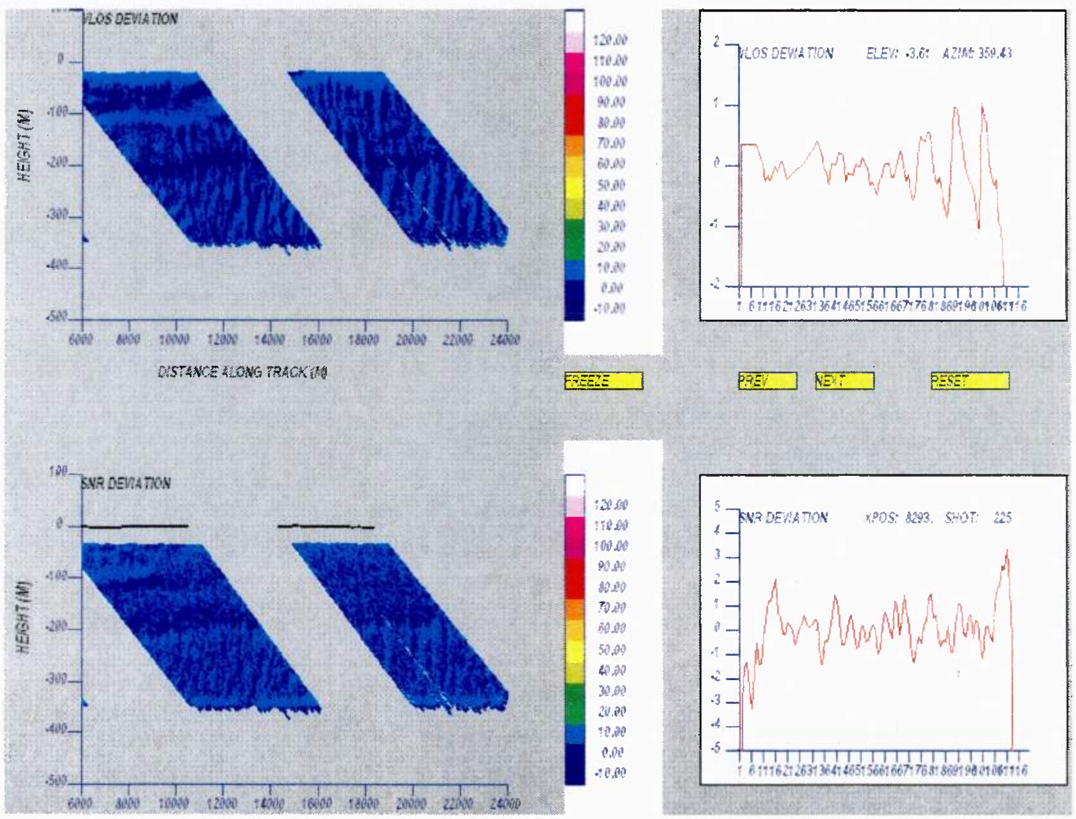




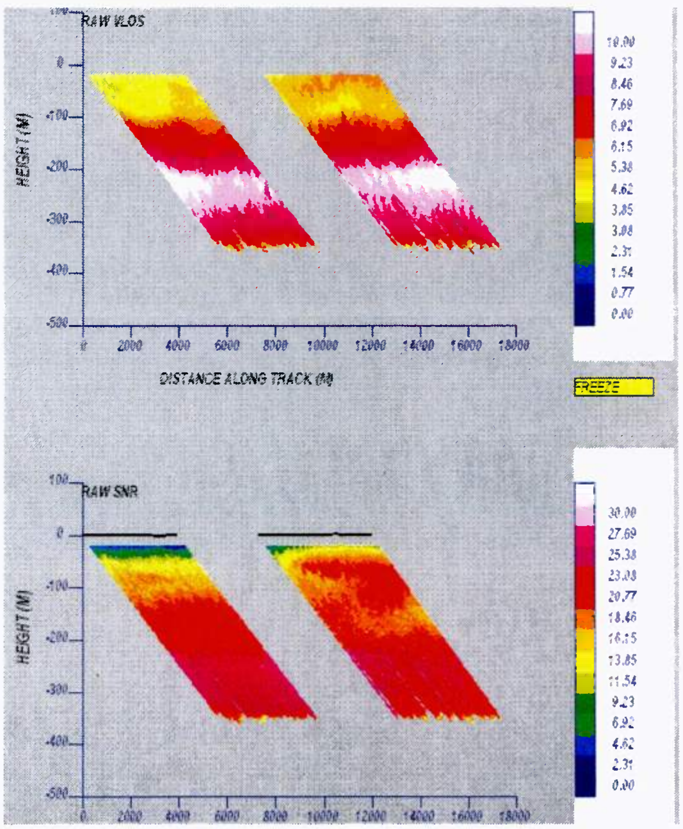
April 13, 2007 flights with CTV


RAW VLOS
HEIGHT (M)
DISTANCE ALONG TRACK (M)
FREEZE
RAW SNR
HEIGHT (M)

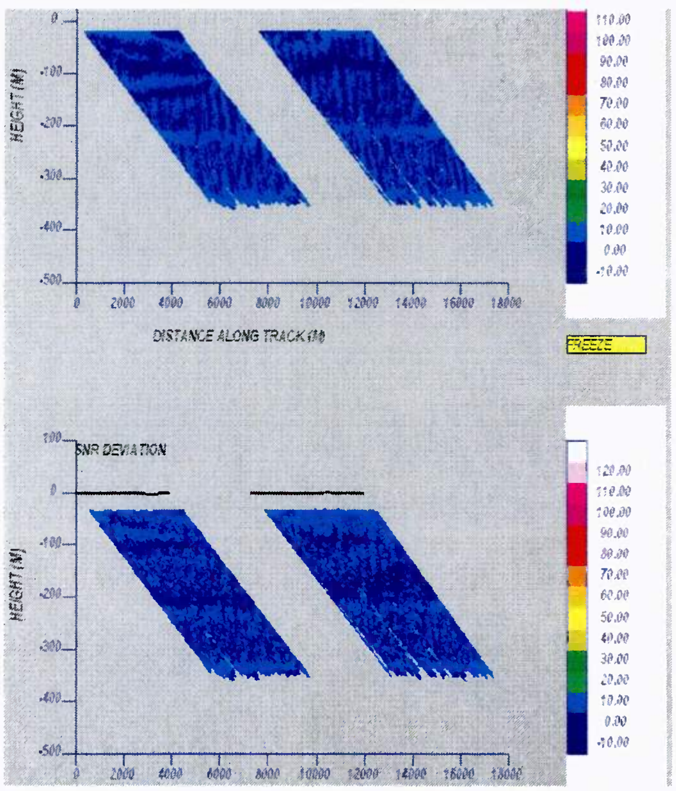
SE



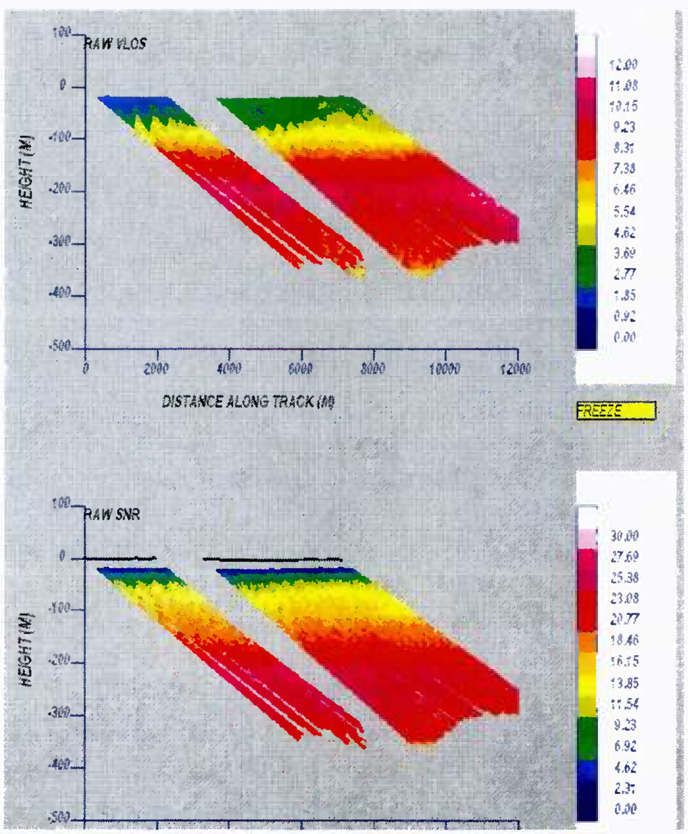
VLOS DEVIATION
HEIGHT (M)
DISTANCE ALONG TRACK (M)
VLOS DEVIATION ELEV: -3.61 AZIM: 359.43
FREEZE
PREV
NEXT
RESET
SNR DEVIATION
HEIGHT (M)
SNR DEVIATION XPOS: 8293. SHOT: 225


RAW VLOS
HEIGHT (M)
0
-100
-200
-300
-400
-500
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
DISTANCE ALONG TRACK (M)
10.00
9.23
8.46
7.69
6.92
6.15
5.38
4.62
3.85
3.08
2.31
1.54
0.77
0.00
FREEZE
RAW SNR
HEIGHT (M)
100
0
-100
-200
-300
-400
-500
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
30.00
27.69
25.38
23.08
20.77
18.46
16.15
13.85
11.54
9.23
6.92
4.62
2.31
0.00

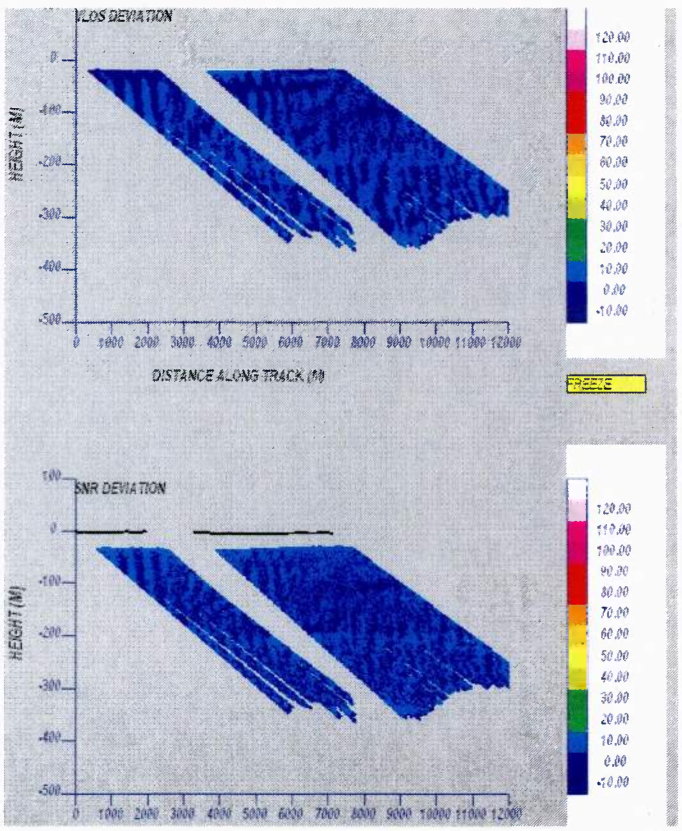
NW



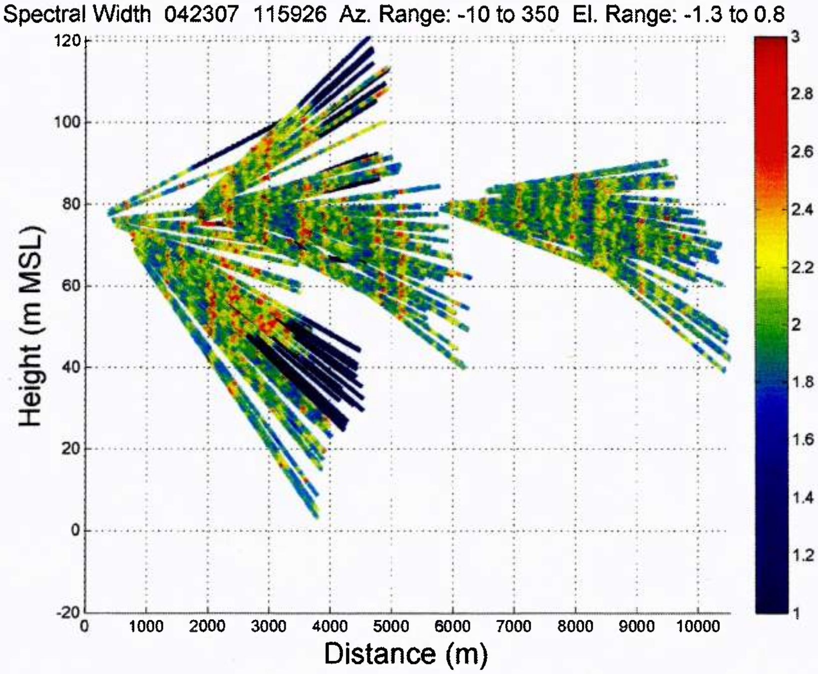
"Stacked-OLEs" or rolls operating in both the negative and positive shear Layers associated with a PBL jet.


RAW VLOS
HEIGHT (M)
100
0
-100
-200
-300
-400
-500
0
2000
4000
6000
8000
10000
12000
DISTANCE ALONG TRACK (M)
12.00
11.08
10.15
9.23
8.31
7.38
6.46
5.54
4.62
3.69
2.77
1.85
0.92
0.00
FREEZE
RAW SNR
HEIGHT (M)
100
0
-100
-200
-300
-400
-500
30.00
27.69
25.38
23.08
20.77
18.46
16.15
13.85
11.54
9.23
6.92
4.62
2.31
0.00

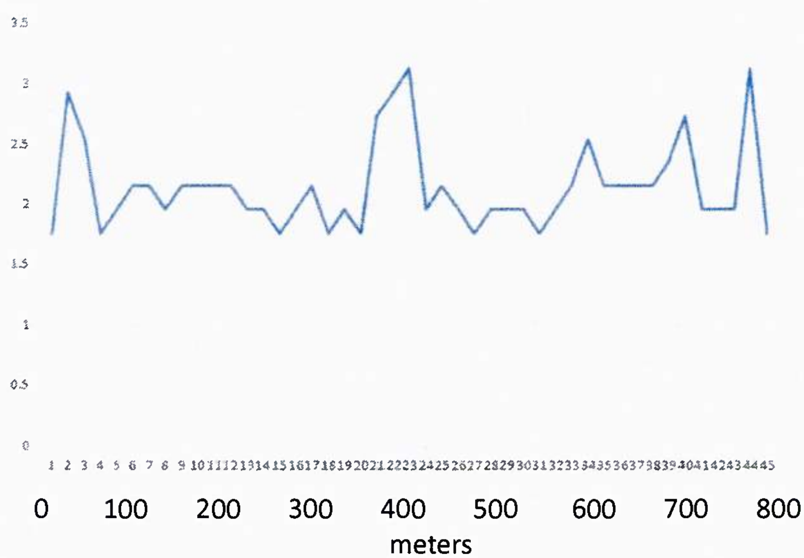
NW

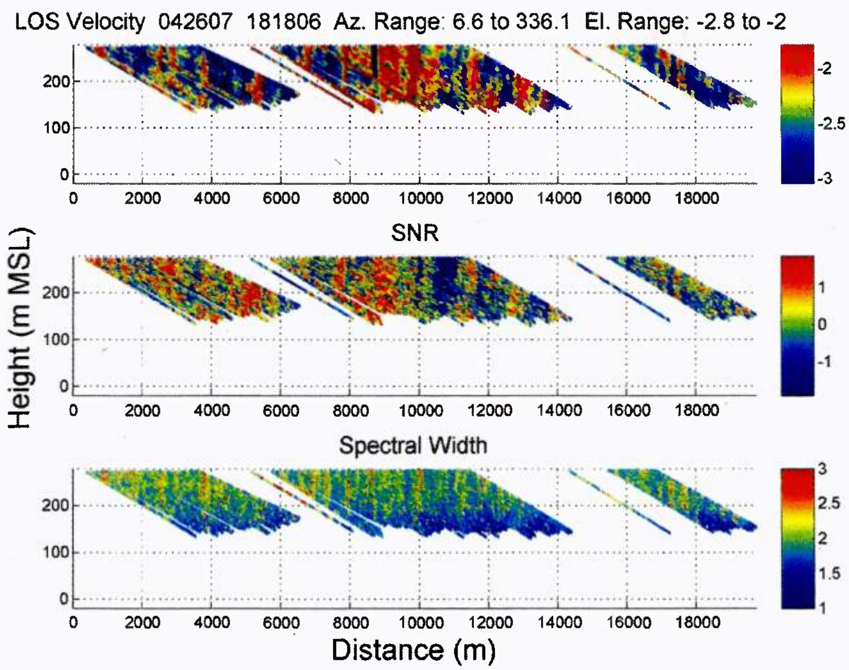

VLOS DEVIATION
HEIGHT (M)
DISTANCE ALONG TRACK (M)
FREEZE
SNR DEVIATION
HEIGHT (M)

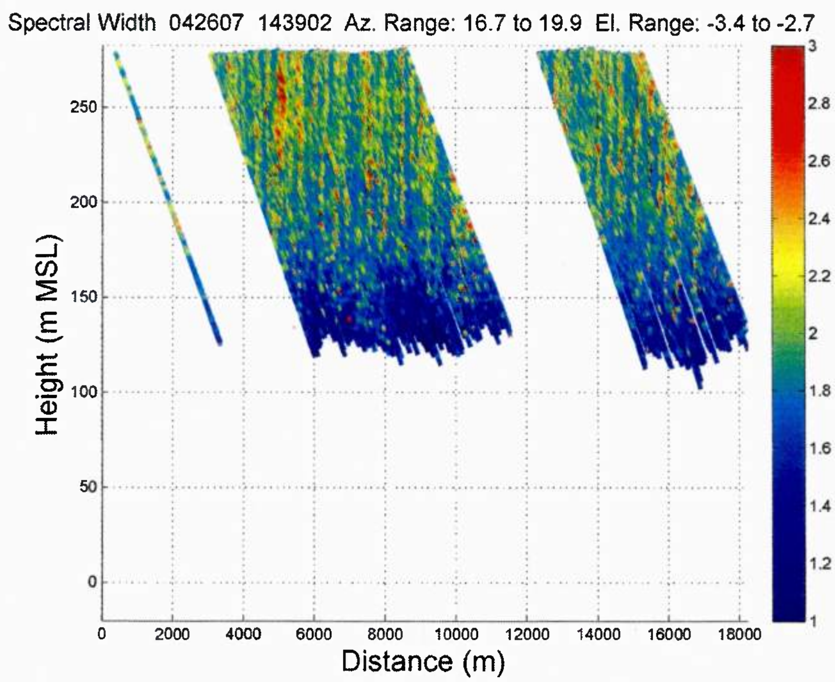
Spectral Width 042307 115926 Az. Range: -10 to 350 El. Range: -1.3 to 0.8

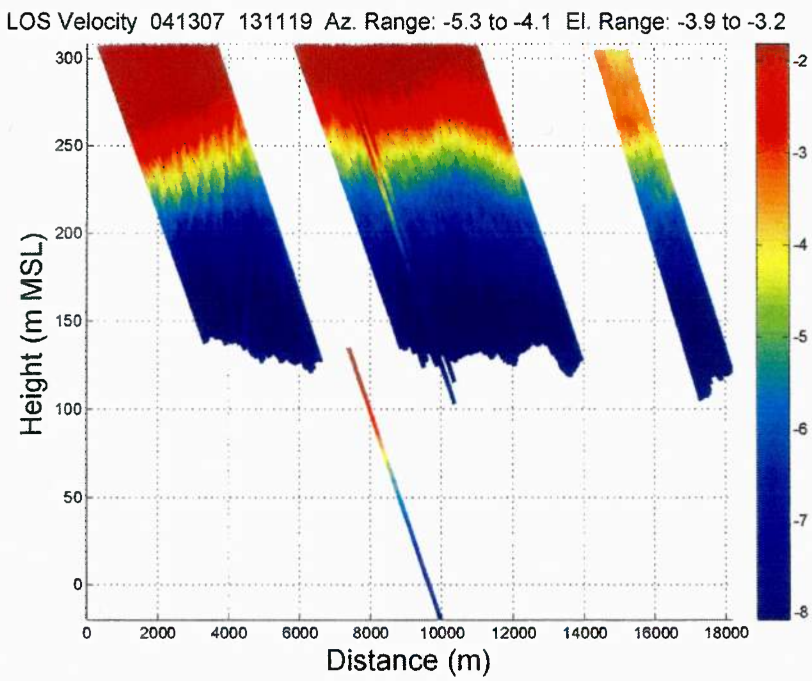


Single level, single shot LOS SB series




LOS Velocity 042607 181806 Az. Range: 6.6 to 336.1 El. Range: -2.8 to -2
SNR
Spectral Width
Height (m MSL)
Distance (m)


Spectral Width 042607 143902 Az. Range: 16.7 to 19.9 El. Range: -3.4 to -2.7
Height (m MSL)
Distance (m)
0
50
100
150
200
250
2000
4000
6000
8000
10000
12000
14000
16000
18000
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3



LOS Velocity 041307 131119 Az. Range: -5.3 to -4.1 El. Range: -3.9 to -3.2
Height (m MSL)
Distance (m)
300
250
200
150
100
50
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
-2
-3
-4
-5
-6
-7
-8

General physical characterization of the rolls with focus on TKE channels.

- General description
  - Only in regions of convergence, no exceptions found in available data
  - Usually detectable via aerosol backscatter structures; aerosol structures appear to outlast velocity structures; same goes for TKE channels.
  - Lidar suggestions that the channels are more slab like than plume-like; consistent with roll geometry.
- Width of turbulence channels
  - 50 -100m with very little broadening throughout vertical extent
- Vertical extent of channels
  - Usually starting very near the surface, but not always (stacked rolls)
  - Not all channels are traceable from surface to top of BL (best described with a PDF)
- Turbulence intensity
  - Difficult to interpret from spectral broadening (SB).
  - Contrast ratio with adjacent SB fairly consistent at 2 – 3.
- Vertical velocities
  - Based upon 2-D convergence calculations, w ranges from .5 – 3.5 m/s
  - Based upon CTV flown at low altitudes (~50 m), very hard to measure but on order .2 - .5 m/s

Investigation of rolls in deep convective boundary layers over land

- MATERHORN (2012)
  - Three TODWL flights with segments in prospecting mode
  - UVa student working on a paper with de Wekker

- Salinas Valley (November 11, 2007)
  - Examples of nearly pure shear driven rolls under stable nighttime conditions

MATERHORN: Case Study

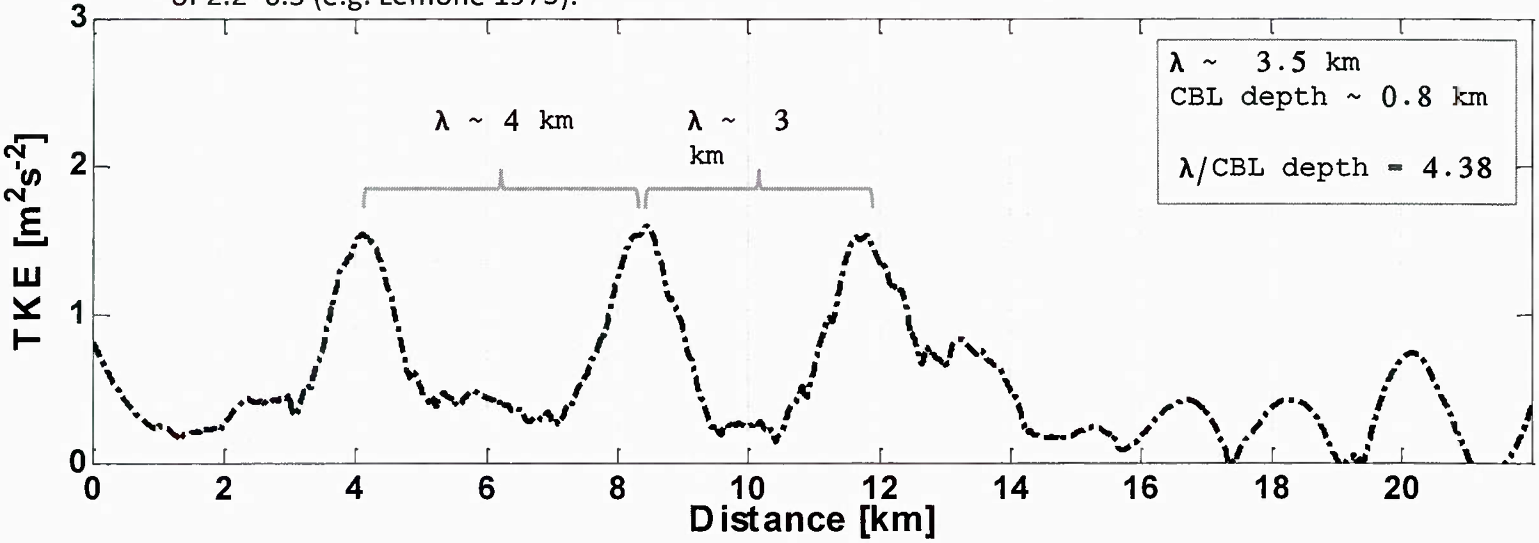
- Twin otter airborne *in situ* observations of meteorological variables (w, θ, and q) over 6 days in October 2012.
- Flight legs over 5 regions over and around an isolated mountain, Granite Peak
  - Sagebrush
  - Eastern Slope
  - Playa
  - Granite Peak
  - Gap
- Surface observations from flux tower over Sagebrush
  - Stability parameter $-z_i/L$
  - Sensible heat flux (H)
  - Turbulent kinetic energy (TKE)

MATERHORN: Case study

- Questions
  - Did rolls occur during the MATERHORN Fall campaign?
    - Are the criteria for the environmental conditions for roll formation met?
    - Can we identify rolls from TO aircraft observations?
  - If rolls do occur, how do their size/spacing and magnitude of thermodynamic transport compare with past observed rolls?

MATERHORN: Case study 06 Oct

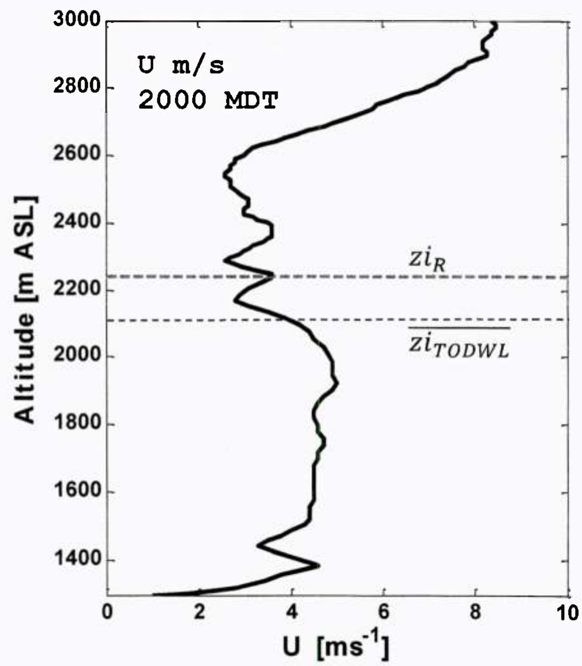
- TKE measured with Twin Otter flux package over the Sagebrush on October 6, 2012 (06Oct) is suggestive of coherent convective structures
- Ratio of wavelength to CBL depth (4.38) is within range of observed aspect ratios of 2.2–6.5 (e.g. Lemone 1973).



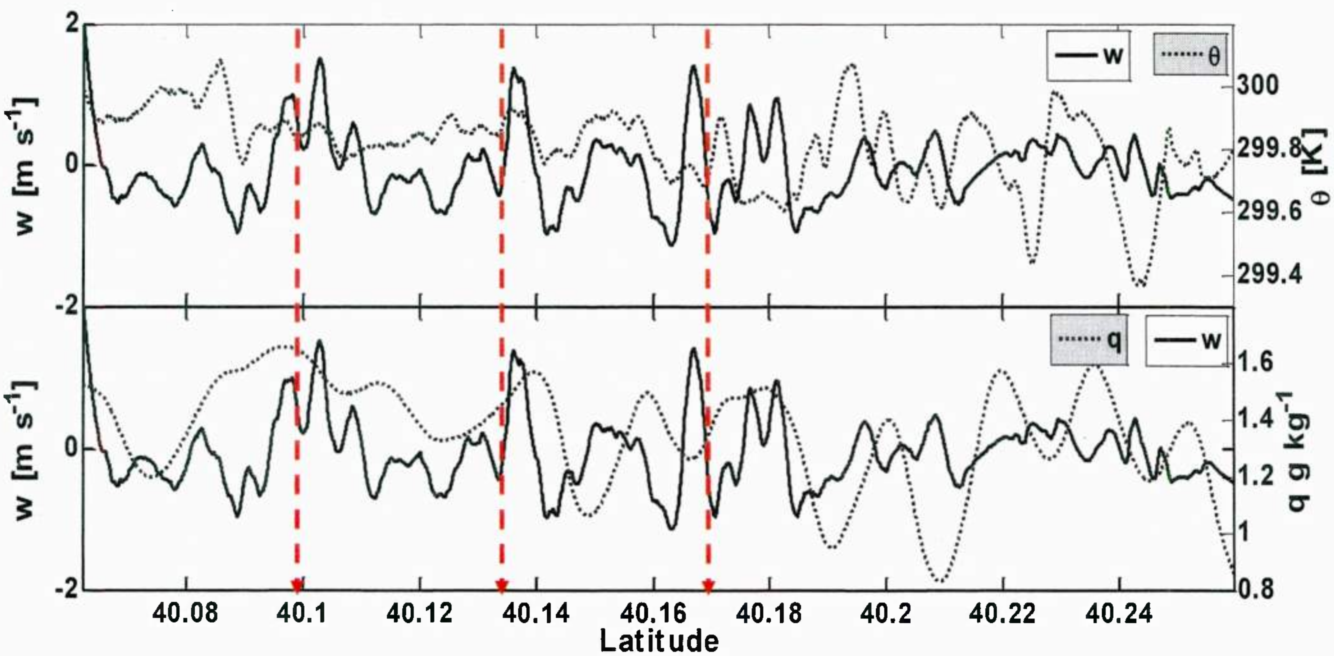
CBL wind speed and shear

- Calculated from surface to zi (1300-2100 MSL)
- CBL wind speed ~ 4.5 m/s
- CBL wind shear is weak

Wind speed profile from Sagebrush radiosonde

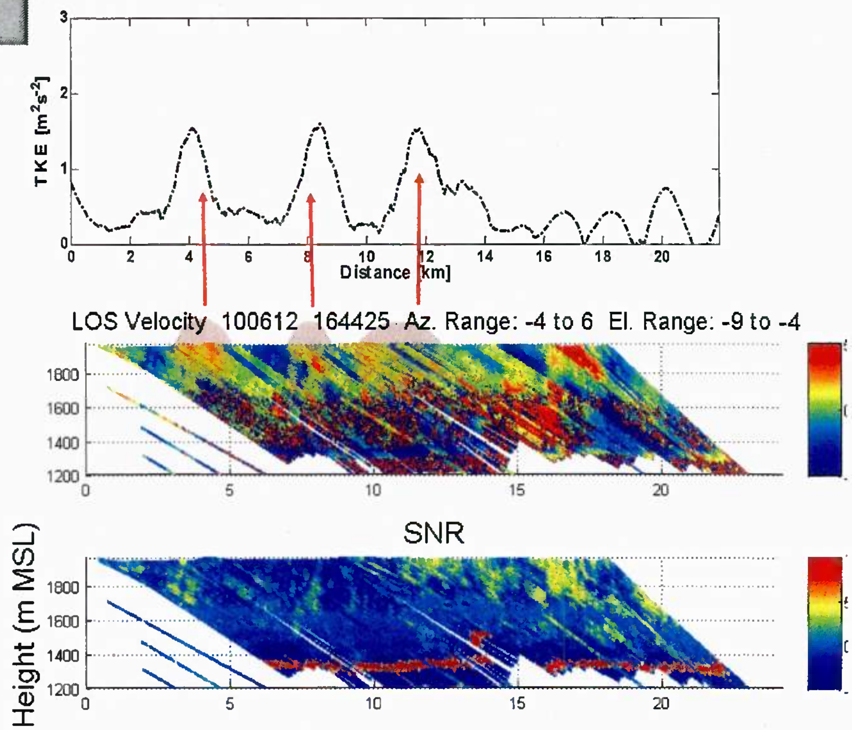


Airborne observations with flux probes



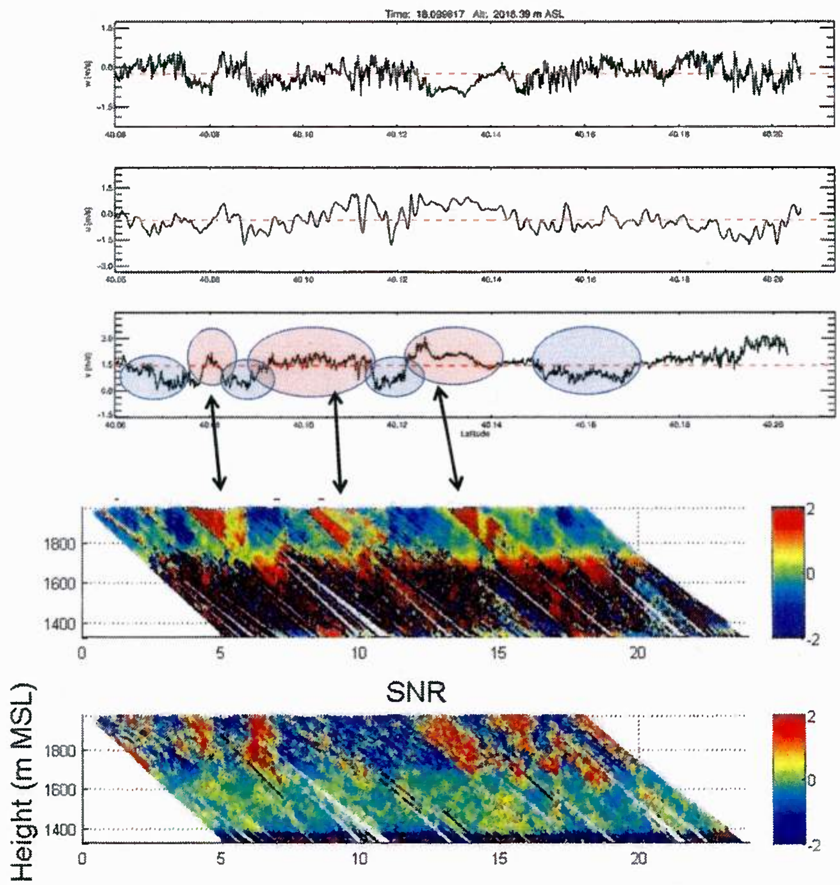
Airborne observations

- Difficult to distinguish features in LIDAR output
- Regions of increased LOS velocity (*red shaded regions*) could possibly be linked to maxima in TKE field
- Unable to tell for certain if linked to convective rolls.
- Need information indicating if these structures are linear in nature



Other potential roll case on 14 October afternoon flight over Sagebrush

Surface sensible heat fluxes lower than on 6 October and zi/L smaller than on 6 October



Summary of physical attributes

- Aspect ratio λ/CBL depth
  - ~ 4.38
- Surface H flux
  - ~ 250 W m-2
- Stability
  - -zi/L ~ 100
- Wind speed and shear
  - ~ 4.5 m/s
  - ~ 2.5 x $10^{-3}\ s^{-1}$

Conclusions

- Thermodynamic variability associated with updrafts and downdrafts is small compared to previous studies
  - Vertical velocity
    - ~ 1.5 m/s
  - Theta
    - ~ 0.1 - 0.2 K
  - q
    - ~ 0.4 – 0.5 g/kg
- Relationship between thermodynamic variables and updrafts and downdrafts is not particularly strong
- Nonetheless, the observed variability fits within limits that past studies have observed

OLE in Mass Flux Framework

- Organized Large Eddies are the result of mixed shear and convective instabilities
- Quasi-equilibrium
  - Persistent overturning circulation in cross-wind plane
    - Upward branch removes slower near-surface winds
    - Downward branch brings higher near-PBL-top winds
  - Low skewness ($\sigma \sim 0.3$ to 0.45)
  - Highly coherent in along-OLE direction
- PBL mean wind and buoyancy profiles determine
  - Generation
  - Quasi-equilibrium state
  - Wavelength 2.5 to 10 times PBL depth
  - (U,V,W) perturbations ~ (0.20, 0.07, 0.04)***V**

Add Momentum to MF

- Zhu (2008) investigate OLE in hurricane PBL using WRF-LES
  - Outer domains used YSU (K-profile) PBL
  - Poor representation of turbulent fluxes of u,v,θ,q
- Proposed MF-like model for OLE contributions
  - Suggested using prescribed $w^2 = w^2(z)$
  - Diagnosed lateral entrainment, $\varepsilon \sim O(10^{-2})\ (m^{-1})$
- Model effect with assumed velocity perturbations associated with updraft
  - Physically, momentum perturbations are not tied to surface properties

EDMF Column Model

- Witek et al. (*JAS*, 2011a,b)
- ED diffusion based on tke
  - MF contribution to tke due to $\frac{1}{2}\overline{ww^2}$
  - Mixing length $l = l(tke)$
- MF contribution of θ, q
  - θ, q and w all determined by surface fluxes
- Constant updraft fraction $\sigma = 0.1$
- Lateral entrainment in convective plumes
  - $\varepsilon = \varepsilon(tke) \sim O(10^{-3})\ m^{-1}$

MF Parameterization Assumptions

$$\overline{\psi} = \sigma\psi_{up} + (1-\sigma)\psi_{down}$$

$$M = \sigma(1-\sigma)(w_{up} - w_{down})$$

$$M = \sigma w_{up} \quad \text{if } \overline{w} = 0$$

$$\frac{\partial U_{up}}{\partial z} = -A\varepsilon(U_{up} - \overline{U})$$

A ~ 50 to account for momentum exchange

$$\overline{w\psi} = M(\psi_{up} - \psi_{down}) = \frac{\sigma}{(1-\sigma)} w_{up}(\psi_{up} - \overline{\psi})$$

Momentum Equations

$$\overline{w\psi^2} = M(1-2\sigma)(\psi_{up} - \psi_{down})^2$$

$$= \sigma w_{up}\left[1 - \left(\frac{\sigma}{1-\sigma}\right)^2\right](\psi_{up} - \psi_{down})^2$$

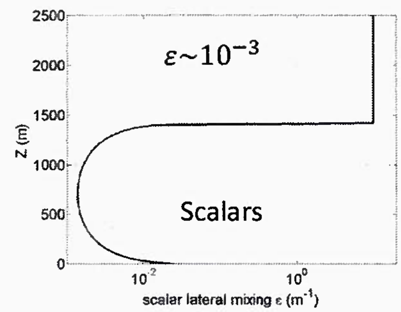
TKE Equation (small effect)

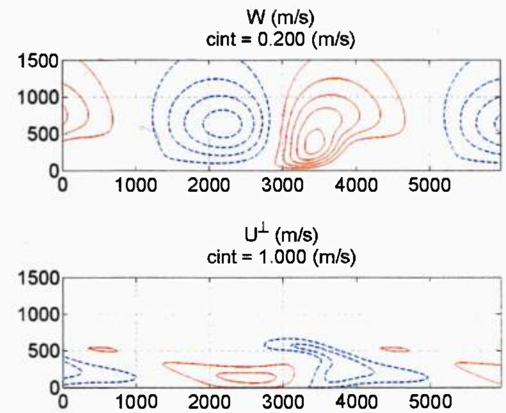
→ 1 if $\sigma \ll 1$(convection: σ=0.1, constant)

→ Need full term for OLE (σ~0.3, not constant)

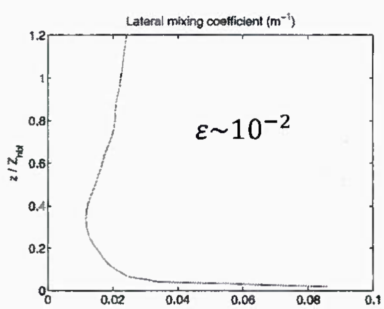
Insert $\frac{\partial}{\partial z}$ as source terms into EDMF model

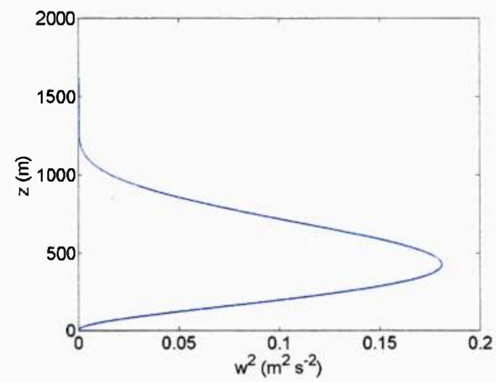
EDMF: $\varepsilon = \varepsilon(tke)$

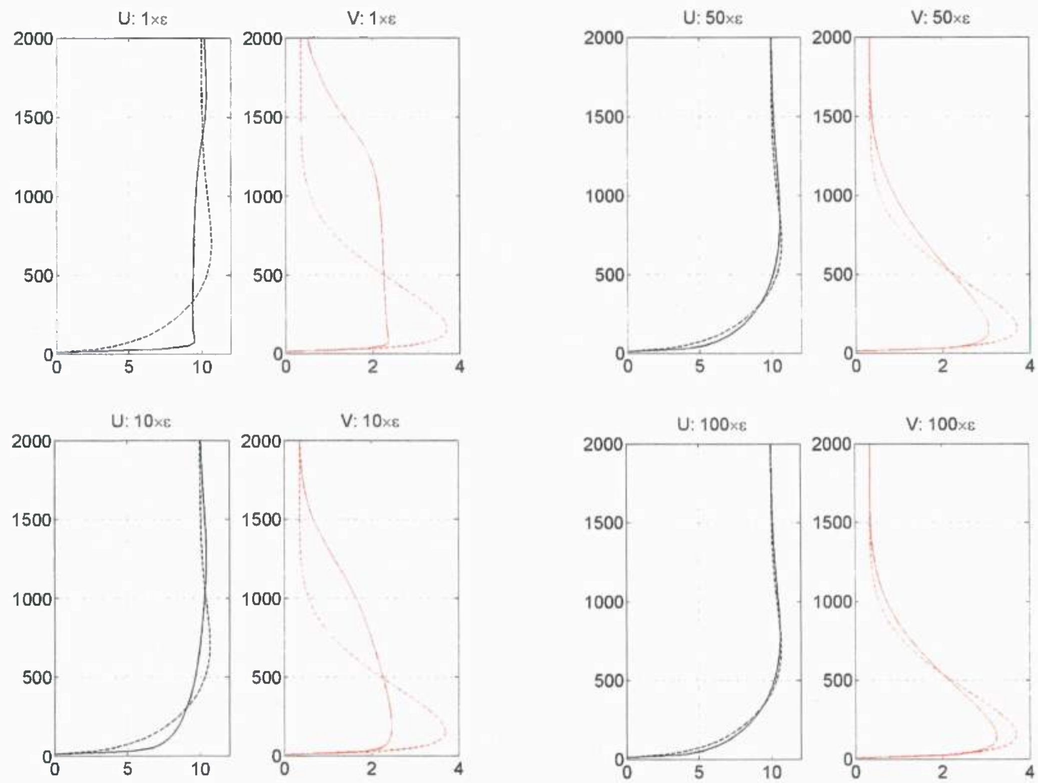




Zhu (2008)







U: 1×ε
V: 1×ε
U: 50×ε
V: 50×ε
U: 10×ε
V: 10×ε
U: 100×ε
V: 100×ε

Discussion

- Consistent with OLE theory, MF parameterization enhances near-surface wind and reduces near-surface inflow
- MF diffusions contribution to *tke* equation is relatively weak (for this largely shear-driven case)
- MF parameterization is very sensitive to lateral entrainment
- OLE horizontal velocity perturbations are not exactly in phase with vertical velocity perturbations
- Bottom-up focus is inconsistent with OLE dependence on full PBL profiles
  - OLE are shear-dependent, not purely convective

Final phase of DRI funded effort for this sub-focus area (role of rolls in EDMF)

- Finish the compilation of the summary document of MBL OLEs as observed with an Airborne Doppler Wind Lidar over coastal waters.
- Construct PDF description of OLE features
  - Physical dimensions (including % coverage)
  - Energetics (e.g. PDF of w at Zi/2)
- Publish a paper (Emmitt and Foster) on the TKE channels
- Two papers in progress at Uva (de Wekker, Emmitt and Pal; de Wekker, Emmitt and Marks)
- Design an airborne field experiment to answer the following questions:
  - How do the momentum and enthalpy fluxes vary within the ADWL resolved features associated with MBL rolls?
    - Are stacked rolls common with MBL jets? If so, what are the impacts on the mass flux parametrizations. Do LES models properly capture the energetics and transports of these features?
  - What attributes of the rolls seen with the ADWL are adequately represented by the EDMF (current form); which are not and merit incorporation into the EDMF parameterization?